A STUDY OF VARIATION IN THE APPLE

W. J. YOUNG

ASSISTANT HORTICULTURIST, WASHINGTON EXPERIMENT STATION

As a rule the subject of variation in the several characters of the apple has been given but incidental attention, and that usually in connection with the study of other problems. As a result the literature on the subject is of a fragmentary character consisting usually of a few observations here and there in papers dealing with other subjects.

It is perhaps worth while to note a few of the investigations which have thrown some light in an incidental way upon the causes of variation in apples. In fertilizer tests which were made at the New York Geneva station[1] and elsewhere, no well-defined and uniform influence of the various elements of plant food upon the color could be detected, though the New York station reports more decided results in seasons when the natural conditions were unfavorable to the development of highly colored fruit. In the comparison of tillage and sod mulch in an apple orchard, also conducted by the New York Geneva station,[2] it was found that the fruit from an orchard in sod was more highly colored and matured one to three weeks earlier than that from the tilled plot, though the latter was better in quality and kept four weeks longer in common storage. The influence of the stock upon the character of the fruit is a matter of much obscurity, the investigation of which presents such difficulties that it has received little attention. The effect of pollination also is still far from settled. It was thought at one time that the characters of the fruit were profoundly modified by the pollen received by the blossom. The data on this

[1] Bull. 289.

[2] Bull. 314.

subject have been collected by Munson,[3] who found that evidence that the pollen has any direct effect upon the fruit is largely lacking. Aside, then, from indirectly modifying the size of the fruit, the influence of the pollen, in so far as our present knowledge goes, may be left out of account in a study of apple variation.

Without doubt the most noteworthy contributions to the knowledge of apple variation are the recent papers by Shaw, of the Massachusetts station, and Stewart of the Pennsylvania station. Shaw's first paper, which appeared in the Massachusetts station report for 1910, deals entirely with the variation of the Ben Davis apple. In comparing specimens grown in a number of widely separated localities it was noted that variations due to climatic condition were strongly marked and affected practically all characters of the fruit. Modifications of form were especially noticeable The depth of coloration was looked upon as correlated with latitude, being pink in the specimens from Arkansas and deep crimson in those grown farther north. The amount of overcolor seemed to be controlled by local conditions. The color was especially good in the apples from the Pacific coast and those from Colorado, Pennsylvania, and Indiana. In a given orchard temperature appears to be the most influential factor governing size. The flesh was notably white in the fruit from Colorado. The apples from Colorado and California were less firm than those from other localities. The southern-grown specimens were more juicy and of better quality than those from the north, which were apt to be dry, hard, flat, and sometimes astringent. It appears that a mean temperature of at least 60° F. for the growing season is required for the satisfactory production of the Ben Davis. The poor quality of the northern-grown specimens is apparently due to a lack of sufficient heat to properly develop the fruit.

In Shaw's second paper in the Massachusetts station report for 1911 the fact is emphasized that the grower

[3] Me. Sta. Rept. (1892), pp. 29–32.

should choose those varieties which he can grow to the highest degree of perfection under his conditions of soil and climate. The causes of variation are summarized, giving special attention to the influence of temperature as a factor in the distribution of apple varieties. The northern limit is regarded as fixed by the lowest temperature which the tree will stand, while the effect of summer heat upon the development of the fruit is looked upon as limiting the distribution southward. The elongation of the fruit was found to be correlated with a low temperature for two or three weeks after blooming. A low summer temperature produces greater acidity, higher content of insoluble solids, greater astringency, smaller size, and scalding in storage. The extent of coloration was regarded as decreasing from the center of distribution in passing either north or south, while the intensity of coloration was considered greatest in high latitudes and altitudes. Excessive summer heat results in uneven ripening, premature dropping, rotting on the tree, poor keeping quality, lack of flavor, mealiness, less intense color, and smaller size. For each variety there is a mean summer temperature at which it reaches its highest development.

It will be noted that Shaw's method of investigating the problem consisted in securing fruit for comparison from widely separated localities and attempting to correlate the various characters with the conditions of production. Stewart, on the contrary, confined his study to apples grown in one locality and noted the effect of modifying one at a time those factors within his control. This is the more scientific method of procedure, but has the disadvantage that the variations are far less striking and a smaller number of factors can be studied. An account of Stewart's experiments and the results so far attained is found in the reports of the Pennsylvania station since 1907. These papers deal largely with the effect of fertilizers and different cultural methods on the yield, color, size and growth of the apple. The various factors influ-

encing these characters are enumerated and the results are given of the studies made of them. It is noted that the factors are so interrelated that the best conditions for producing one effect are often injurious in some other direction and that the chief problem in orchard management is a proper balance of the various factors. An "optimum principle" is recognized, according to which plant growth and development increase as the most distant essential factors approach the optimum. The factor farthest from the optimum, therefore, whether below or above, may control the results from a crop

OUTLINE OF THE EXPERIMENT

Since the season of 1912 was one of full crop in nearly all centers of apple production, conditions were especially favorable for the study of variation in this fruit. The writer accordingly obtained specimens for study and comparison grown in a number of localities under quite dissimilar conditions. The method employed was therefore that of Shaw, as pointed out in the last paragraph, rather than that of Stewart. The study has been pretty largely confined to Washington-grown apples, though a few have been obtained for purposes of comparison from the east and middle west. The formal investigation of the problem has been carried on but a single season, which is entirely too brief a study to demonstrate conclusively all points touched upon. The conclusions reached, however, are strongly supported by many observations in various localities extending over a number of seasons, and are so suggestive of further lines of study as to justify a report at this time.

In carrying on this investigation the aim has been to secure as much information as possible regarding the conditions under which the fruit was grown. The endeavor has been to get into communication with the growers and obtain from them through correspondence data regarding the character of the soil, rainfall, irrigation, elevation, exposure, temperature, age of trees, fertilization and

cultivation. The chief line of observation had to do with the variations which occur in the different samples of the same variety as obtained from different sources. To get at this side of the problem, careful observations were made as to the condition of the apples, and their various characters were recorded in a complete technical description of each sample for the purpose of making a comparative study of the samples of the several varieties. In addition to this written description, photographs were made showing typical specimens in various positions and when cut in cross and longitudinal sections. In general it may be said that variations are found in the form, size, color, internal structure, texture, flavor, quality, specific gravity, chemical composition, time of ripening, and keeping quality. The attempt is made to correlate these characters with the conditions of growth in so far as they are known and to work out the law of the relation of environmental factors to the characters of the fruit.

The following apples were made use of in the study: Arkansas, one sample; Arkansas Black, one sample; Baldwin, eight samples; Ben Davis, nine samples; Delicious, three samples; Esopus, seven samples; Gano, seven samples; Grimes, seven samples; Jonathan, eight samples; Lawver, one sample; McIntosh, one sample; Northern Spy, seven samples; Rhode Island Greening, three samples; Rome, eleven samples; Stayman, five samples; Tompkins King, four samples; Wagener, six samples; White Peamain, three samples; Willow, one sample; Winesap, ten samples; Winter Banana, one sample; Yellow Bellflower, four samples; Yellow Newtown, seven samples; and York Imperial, two samples, making a total of 117 samples embracing 24 varieties. These apples were obtained from fourteen localities in the state of Washington and also from one locality in each of the following states: New Hampshire, Indiana, Missouri, New York, and West Virginia.

Before leaving the preliminary portion of this paper the writer wishes to express his appreciation of the aid

received from those who have helped in various ways in the investigation. Thanks are due to the members of the staff of the department of horticulture for suggestions and encouragement, to the members of the library staff who have rendered aid in the study of the literature of the subject, to Mr. Geo. A. Olson, chemist of the experiment station, who has analyzed the various samples of Grimes, Jonathan, Yellow Bellflower, and Winesap, and finally to the various fruit growers and others who have cooperated in securing the fruit and have furnished notes on the conditions of production. To all these the writer takes pleasure in acknowledging his gratitude and indebtedness.

ENVIRONMENTAL FACTORS

Aside from small individual differences, better called fluctuations than variations, and other more striking modifications of comparatively infrequent occurrence and obscure origin, which it is customary to explain as bud variations, if, indeed, the application of a name to a phenomenon can pass as an explanation, it is quite generally recognized that variation in any variety of fruit is due to the operation of external influences. A knowledge of the various factors which make up the environment and their influence upon plant life is necessary to an intelligent study of variation. It should be noted, however, that this influence is not necessarily the same with plants propagated vegetatively as with those grown from seed. In the latter case certain modifications of an adaptive nature which enable the plant to fit in more perfectly with its surroundings are apt to persist, while less favorable modifications tend to disappear by the elimination of the individuals possessing them. In the former case, on the other hand, the modifications observed are the direct result of the conditions, unaffected by selection, and whether desirable or not they persist as long as the environment is unchanged and the vegetative propagation is continued, unless, indeed, the environment is so unfavorable that the

changes induced are pathological in nature and the plant can not survive.

Perhaps the most important factor to which plant life is subjected is the moisture relation. This may be determined by the amount of moisture actually present or by the modifying influence of other coexistent factors which interfere with the availability of the moisture and the capacity of the plant to make use of it. Among such indirect influences may be noted the modifying effect of temperature upon the rate of absorption and transfer of moisture, the presence in the soil of certain salts or humic acids which interfere with the osmotic activity of the roots, and certain atmospheric conditions favorable to rapid transpiration. In such cases care is necessary to determine which is the direct and which the indirect cause of the modifications. If it is borne in mind that many factors cause variation through their influence on the moisture supply confusion may often be avoided.

The temperature relation is much more obscure than the moisture relation in its effect upon plant growth. Heat, being a molecular phenomenon, acts directly upon the protoplasm and its effects are therefore physiological. It is now pretty well understood that heat alone is incapable of modifying plant structure, but acts indirectly through other factors and the functions of the plant. The direct effect of temperature is limited very largely to its influence upon the rate and amount of development. A slight difference in the average temperature of the growing season influences greatly the relative development of apple varieties. The accompanying table gives the mean monthly temperature during the growing season at Geneva, N. Y., and Pullman, Wash., since the establishment of the experiment stations at those points, as well as the mean for two years at White Salmon, Wash.

Locality.	April	May	June	July	Aug.	Sept.	Oct.	Aver.
Geneva, N. Y.....	44	57	67	71	69	63	50	60
Pullman, Wash.....	47	52	59	66	66	58	48	57
White Salmon, Wash..	50	56	63	70	67	60	53	60

The difference in the development of certain varieties of apples at these places will be noted later. It will be seen that the season opens slightly earlier in Pullman than in Geneva and closes at about the same time. It would appear, therefore, that the better development of most varieties at the latter station is due rather to the higher temperature than to a difference in the length of season. At White Salmon the season is considerably longer than at either of the other stations, while the temperature from May to September is intermediate.

Latitude and altitude are frequently mentioned as important factors in the modification of varieties. These, however, are not primarily factors, but depend for their influence upon the effect of other factors, which in turn are influenced by the location. Differences in altitude especially result in marked changes in climate often in places geographically near together.

The light relation is of much importance to the fruit grower. It is clearly evident that the development of color in apples is largely dependent upon the sunshine, and quality also may be affected through the production of sugars. Both intensity of insolation and duration of the daylight must receive consideration. In general, tropical, arid or alpine situations are characterized by high insolation, while a long period of daylight during the summer months is a factor in northern latitudes.

The effect of atmospheric influences is largely indirect. It has already been noted that the condition of the air may modify the moisture relation through its effect upon transpiration, thus dryness, high temperature, and rarification all favor evaportion, and this effect may be increased in windy situations. Atmospheric pressure is a factor of importance in high altitudes.

The soil may be of importance as a factor in causing variation through either its chemical composition or its physical properties. The former leads to a consideration of the influence of fertilization, the latter to the effect of different methods of culture. Here again other factors,

and especially the moisture relation, have an important bearing, since one of the primary results of cultivation is the conservation of the soil moisture. There is no doubt that the nature of the soil greatly affects the crop and the matter has been given much study. The intimate association of other factors, however, makes it somewhat difficult to pick out those influences for which the nature of the soil is directly responsible.

The influence of other organisms includes not only a consideration of the effect of insect and fungus pests but in the broad sense embraces such items as pollination, pruning and thinning, intercrops, cover-crops and planting distance. Human agencies, including all operations of orchard management, might properly be included here. Many of these are, of course, indirect, exerting an influence through their effect upon some other factor.

The Law of the Optimum

Having enumerated the chief external influences to which plants are subjected during their period of development and to which variation is largely due, the question naturally occurs whether there can be formulated any basic principle or law which will express the manner in which plants react with the environment. Such a law would be of use not only in the study of variation, but would shed much light on the adaptation of plants to new environments. It would constitute a unifying principle whereby isolated facts and disconnected observations appear in proper relation and perspective. Though a discussion of this subject might logically be delayed until after the characters of the several varieties and their modifications have been noted, it is thought most fitting to introduce the statement at this point and examine the fruit in the light of such generalizations as it has been possible to make.

A plant can live and perform its functions only within certain intensities of the various factors of the environment. The degrees of intensity beyond which activity

ceases are known as the *zero points*. The plant does not necessarily die at once, but passes into a dormant state. If the intensity becomes still more unfavorable a point is finally reached at which death occurs. The minimum degree of intensity of a factor at which the plant may remain active is known as the *lower zero point*, while the greatest intensity is called the *upper zero point*. With some factors these points are wide apart, so that, other conditions being favorable, the plant will continue to develop after a fashion at any but the most extreme intensities of such factors. With other factors the limits are comparatively narrow. A plant will reach that degree of development only which is permitted by that factor which is in the least favorable degree of intensity. Such factors are called *limiting factors*. In passing from one zero point toward the other, a point is finally reached at which any given function of a plant reaches its highest state of activity. This point is known as the *absolute optimum* for that function and may not correspond to the most favorable intensity of that factor for the performance of the other functions of the plant. The point of intensity of a factor at which all the functions of the plant are performed to the best advantage is termed the *harmonic optimum*. If each factor is of an intensity corresponding to the harmonic optimum, the plant is in a condition of equilibrium known as the *ecological optimum* and will reach the highest state of activity of which it is capable.[4]

As the life of a plant is made up of various functions, so its structure is made up of a number of organs having various characters. These characters are the result of development, which in turn is dependent upon the performance of the several functions of the plant under the influence of those external conditions which make up the environment. If a factor of the environment is modified in its intensity, the balance of the functions of the plant is disturbed and the plant reacts to its changed environment by a modification of its functions which may result

[4] Schimper, A. F. W., "Plant Geography."

in a different kind of development, or in other words a variation. Having observed the close connection between the characters and the functions of the plant, we may now inquire whether the former maintain a relation to the environment similar to that maintained by the latter. Putting aside generalizations for the present and confining attention to the apple, it is to be noted that both Shaw and Stewart foreshadowed such a relationship in the papers already noted. Neither, however, carried the analysis far enough to formulate a rule of general application, though Stewart came near doing so. Shaw recognized that the highest perfection in any given variety could be attained only under the most favorable summer temperature. Stewart applied this idea to other factors than temperature in his "optimum principle," which is "that plant growth and development increase as the most distant essential factors approach the optimum." His failure to recognize the connection between the various factors of the environment, on the one hand, and the separate characters of the apple, on the other, may be accounted for by the fact that his investigations dealt only with fruit grown under slightly modified conditions, which resulted only in such slight variations that the independent modification of the separate characters escaped notice.

In examining various samples of apples produced under the influence of quite dissimilar combinations of environmental factors, the writer has many times noted the modification of certain characters more or less independently of others. It is true that characters are often found to vary together through a relationship of direct or inverse correlation. Such cases, however, are possibly as often due to the response of the various characters to the same factor of environment as to any direct connection between the characters, though the latter no doubt exists in many cases. Keeping in mind these facts and also the close relationship of function and character, the writer has formulated a principle which he believes is of general application not only to apples but to other horticultural

crops and perhaps in a degree to all plant life. For this generalization, which expresses the relationship of characters to environmental factors the name "Law of the Optimum" is proposed.

This law may be stated as follows: For any given variety there is for each character a certain intensity of each essential factor of the environment at which, other conditions remaining the same, that character reaches its highest development. When all essential factors are in a condition of optimum intensity for any character, that character will reach the most perfect development of which it is capable. A modification of the intensity of any such factor either above or below the optimum will be accompanied by a less perfect condition of the character concerned. The optimum intensity of a factor may be wide or narrow in its limits and the optimum for one character may or may not overlap the optimum for others. A variety will be at its best when grown in an environment the factors of which are as near as may be to the optimum intensity for all characters. Under such circumstances the variety is in a state of *balanced adaptation* to its environment. If removed from such an environment to one in which certain factors are distant from this state of average optimum intensity for all characters, the equilibrium is destroyed and the variety is thrown into a state of *unbalanced adaptation,* in which those characters farthest removed from their respective optima are injuriously affected, while others may be bettered by being placed in a combination of factors of an intensity nearer their optima. A discussion of the practical application of this law and its bearing upon apple culture in the northwest will be deferred for the present and taken up in a later section.

A Comparative Study of the Samples

A close study of the various lots of apples used in this experiment brings to light variations in practically all characters. Many, however, are modifications of charac-

ters inconspicuous in themselves or are slight in amount and so do not attract attention. A complete account of all variations noted would comprise a full technical description of each sample which would far exceed the limits of this paper. For this reason it is thought best to append only some brief comparative notes regarding the more conspicuous variations noted in each variety. In this connection it is well to note the origin so far as known of the varieties included in this study. Arkansas and Arkansas Black, Arkansas; Baldwin, Massachusetts; Ben Davis, probably Kentucky or Tennessee; Delicious, Iowa; Esopus, New York; Gano, probably Kentucky or Missouri; Grimes, West Virginia; Jonathan, New York; Lawver, possibly Kansas; McIntosh, Ontario, Canada; Northern Spy, New York; Rhode Island Greening, Rhode Island; Rome, Ohio; Stayman, Kansas; Tompkins King, New York; Wagener, New York; White Pearmain, probably Eastern States; Willow, Virginia; Winesap, New Jersey; Winter Banana, Indiana; Yellow Bellflower, New Jersey; Yellow Newtown, New York; York Imperial, Pennsylvania. It will be observed that all originated in the east or middle west. Most no doubt appeared as seedlings and were selected and propagated because of their excellence and value when grown under those conditions of environment which prevail at their places of origin; in other words they were individuals which happened to be in a condition of balanced adaptation to that environment. Their behavior under other environments could be determined only by actual tests, and some notes on the subject are included in the following paragraphs.

Arkansas (*Mammoth Black Twig*).—As only one sample of this variety was examined its behavior can be compared only with what is known of the variety in other localities. The fruit was more elongated and conical in shape, smaller in size and less highly colored than that produced in the warmer apple-growing sections of the east. The flesh was inferior in texture, indicating poor development. The variety seems not at all adapted to

the location where grown, but might do better at lower altitudes and in warmer situations in the state. Nevertheless, the quality is not good enough to recommend the variety for dessert, and it is to be hoped that it will not be planted extensively in the northwest. The keeping quality was excellent.

Arkansas Black.—This variety of the Winesap group attains a deeper color than the Winesap and equals that variety in size and quality. The specimens examined were not especially well colored though, it is known to color well in the irrigated valleys. It seems to be better adapted to the conditions of the state than the Arkansas. In keeping quality it was among the best.

Baldwin.—The Baldwin attains its highest perfection in New York and New England, where it is a great favorite in the markets and is produced more largely than any other variety. As grown in this state the fruit is smaller and more elongated than the eastern product and has a more deeply furrowed basin. As grown at Pullman the color lacks intensity, though the fruit is well covered. In the western part of the state the fruit is well colored, especially in the northern part of the Puget Sound Basin. The lots from White Salmon show a good many poorly colored fruits mixed with those of better color, while the quality is rather better than in those examined from other parts of the state. It is, however, inferior to the eastern-grown Baldwin and is evidently poorly adapted to the conditions of the northwest. All of the Washington-grown fruit displayed a tendency to wilt in storage and some of the lots from the western part of the state rotted seriously as a result of fungous infections not apparent on the fruit at the time of storage.

Ben Davis.—Though displaying considerable lack of balance in the adaptation of the different characters to conditions in certain parts of the state, this variety seems on the whole to reach a good degree of development in the warmer valleys. In quality the lot from Missouri was superior to those from any part of Washington, though

many of the Washington-grown apples of the variety were equal to those from most sections of the east. Striking variations in form were displayed by the fruit from different localities. Those lots from the more elevated and cooler sections of the state were of an oblong, conic form and usually had shallow irregular basins, while those from the warm valleys were less elongated and had deep and usually quite regular basins, being more like the fruit from the Ben Davis belt of the east. The fruit developed better texture and quality also in the valleys though it was coarser and more spongy than the eastern fruit. Most of the Washington grown samples of Ben Davis were more decidedly striped than those from the east. This effect is produced by the clearer yellow ground color, which in the eastern-grown fruit is more or less suffused with red. The apples from the elevated localities of Pullman, Cloverland and White Salmon were relatively small in size and poorly colored. Because of its low dessert quality, the planting of this variety for shipment to the east can not be recommended. The most desirable feature of the Ben Davis fruit is its good keeping quality. A tendency to mealiness late in the season was observed in some of the fruit from the irrigated valleys, while those grown at Pullman and Cloverland wilted badly toward the close of the season.

Delicious.—This is one of the newer varieties and when well grown is a dessert apple of fine appearance and high quality. In many of its characters, but especially in flavor and aroma, Delicious resembles the White Pearmain, though in color it bears a likeness to the Winesap group. In moderately elevated situations in some parts of the state it displays a well-balanced adaptation and attains excellent size, color, texture and quality, though none of those examined were quite equal in quality to the Delicious from New York. When grown in too low and warm a location the fruit has a tendency to become overripe and when stored tends to soften in the center, after which it loses greatly in quality. The sample from Clarkston had

a beautiful dark red color, while that from Cloverland was dull in color and poor in texture.

Esopus (*Spitzenburg*).—This is almost the only variety which the writer has examined that attains the first rank as a dessert apple in this state. In certain sections it displays a better balance of adaptation so far as flesh characters are concerned than any other variety. The samples obtained from White Salmon and the irrigated valleys were of excellent quality as dessert apples, though of scarcely as good texture as the variety attains in the east. Overgrown apples are especially coarse in texture. West of the Cascades and in the more elevated locations the Esopus does not reach as high quality as elsewhere. This variety is inclined to wilt in storage unless well grown.

Gano.—This is an apple of the Ben Davis type, but of a more uniform red color. Practically all the remarks included under Ben Davis, aside from those dealing with the distribution of color, apply equally well to the Gano. At its best, the Gano is of slightly better quality than the Ben Davis, which fact, together with its more handsome appearance, renders it a more desirable variety to plant, yet neither can be recommended in a section desirous of building up a reputation and market for dessert apples. It is interesting that both the highest color and the best as well as the poorest quality was attained by apples from the east and middle west.

Grimes (*Grimes Golden*).—This variety, like the Ben Davis, displays considerable variation in form, depending on the locality of production. The specimens from the middle west were roundish to decidedly oblate, while those grown in Washington were all more or less elongated. Those grown west of the Cascades displayed a greater tendency to a conical shape than those from the eastern part of the state, and were also poorer in quality. When grown in the more elevated sections, as at Pullman, Grimes appears poorly developed and immature and is inferior in size and quality. Those from Grandview displayed the best balance of characters and it seems prob-

able that this variety is better adapted to the irrigated valleys than to other sections of the state. All samples were more or less wilted by midwinter, except the fruit from Grandview, which remained firm but showed some tendency to rot. Scald was very bad in the latter part of the season.

Jonathan.—Although rather extensively grown in a number of localities in Washington, none of the fruit which the writer has examined gave evidence of a well-balanced adaptation to the conditions of growth which prevail in the state. All were inferior in color to the fruit obtained from the east and middle west. The apples from Clarkston and the Yakima Valley were of good size but lacked both richness of flavor and aroma. The same lack was evident in the fruit from the western part of the state. At Pullman a pretty good quality is attained, but the fruit does not come up to the requirements as to size and gives other evidence of imperfect development. At Cloverland and in other elevated locations fruit of a poor texture and deficient coloring is produced. Jonathan seems to reach its highest development in certain sections tributary to the Ohio valley and the Washington-grown Jonathans can not compete with fruit from that section when well grown. The samples from Morgantown, West Virginia, were of a beautiful clear dark red color, good size, fine tender flesh, and very high quality. In storage these specimens remained firm and retained their flavor until April. The others wilted considerably after mid-winter.

Lawver.—This variety attains good size and fine color in the irrigated valleys, but the quality is not good enough to recommend it to the fruit growers of the northwest. The variety ordinarily keeps well but the specimens stored proved to have poor keeping quality—owing to fungous infection.

McIntosh.—The McIntosh is deserving of attention as a variety of high quality which appears to have a fairly well-balanced adaptation to certain sections of the north-

west. At Pullman the elevation is too great for the best development of the variety, but the Spokane Valley produces McIntoshes of a high degree of excellence. There is good reason to believe that the valley of the northern and northeastern sections of the state can rival the Bitter Root valley of Montana in the production of this variety. The fruit stored wilted badly by midwinter and lost much of its flavor soon after.

Northern Spy.—Of all the varieties examined the Northern Spy seems least adapted to the conditions of growth in this state. As produced in New York and New England this fruit is a dessert apple of the highest quality when well grown and properly colored. In Washington east of the Cascades the color fails to develop and the quality is much inferior to that of the eastern-grown fruit. In the western part of the state the color develops as well as in the eastern states, but the quality is no better than elsewhere in the state. The unsurpassed cooking quality of this variety seems to be largely retained, however, which is its only redeeming feature. It may be worth planting to a limited extent as a culinary fruit for home use, but can not compete in the markets with the eastern-grown Northern Spys. The specimens from the western part of the state were largely infected with fungi, resulting in much decay early in the season. Those from Pullman and Clarkston kept fairly well, though the former wilted badly late in the season.

Rhode Island Greening.—This variety, together with Baldwin and Northern Spy, constitutes the most prominent and successful apples in the orchards of New York and New England. They are also among the varieties least adapted to the conditions found in this state. Their perfect balance of adaptation to eastern conditions is probably to a large degree responsible for their popularity in the east and may also account for the lack of balance which they display in the northwest. As grown at White Salmon and at Pullman the Greening reached a good size, but was decidedly inferior in quality to the specimens

from New Hampshire. At Pullman the fruit was rather flat and strongly ribbed, while at White Salmon the apples were oblong in shape and had, as a rule, rather small cavities. It can not be recommended for Washington, except possibly for local use as a culinary fruit. This variety is a fairly good keeper. Those grown at Pullman wilted badly late in the season, while the lot from White Salmon gave evidence of considerable fungus infection.

Rome (*Rome Beauty*).—This is one of the most popular varieties grown in the state east of the Cascade Mountains and is about the only commercial variety which reaches good marketable size in the high uplands of the Inland Empire. The Rome reaches its highest development in the Jonathan belt of the middle west. The best specimens examined, all characters considered, came from Morgantown, West Virginia. They were of a nearly uniform deep red color, of good size and attractive form, and of pretty good quality for the variety. In many parts of Washington the Rome fails to color well. The specimens from White Salmon and Grandview were especially poor in color. The latter were overgrown and of poor quality, while the former were among the best of the variety. The usual form of the variety is round or nearly so, varying to somewhat roundish conic or roundish ovate. The form of the cavity is subject to quite a little variation. As produced at Pullman and other elevated sections of the state the cavity is very shallow, but becomes deeper in the valleys. The specimens from West Virginia had fairly deep cavities. Indeed it seems probable that those localities which produce Ben Davis of the elongated type also produce Romes with the shallow cavities. The Rome is by nature a culinary apple. In quality it is but little better than Ben Davis. It seems unfortunate, therefore, for the lasting reputation of the industry, that it should have become so firmly established in northwestern horticulture. It is to be earnestly hoped that it may in time be replaced by a variety of better quality. In its adaptations to the conditions of the state, the Rome seems to be fairly well

balanced in most of its characters. The balance, however, is not the same in all sections and is nowhere quite so perfect as in certain localities in the middle states. Most samples kept well until the latter part of the season and then became mealy. The overgrown specimens from Grandview were the first to break down in this way. Those grown at a greater elevation showed a slight tendency to wilt late in the season. None of the samples displayed an inclination to rot until late in the season.

Stayman Winesap.—In both size and quality the Stayman is the best of the Winesap group. Its most serious fault is a rather dull color which often fails to cover the fruit well. The samples obtained from the middle west were of better color and texture than those grown in Washington, though the lot from Indiana were very coarse in texture. Those grown at Pullman were small and inferior in every way. The fruit from Grandview was especially large, flat, and fairly well colored, while that from White Salmon was more elongated, slightly less colored, and rather more aromatic in flavor. These two lots retained their firmness in storage much longer than the others and those from White Salmon scalded badly late in the season. It is very similar to the Winesap in its adaptations.

Tompkins King.—This variety is popular in the western part of the state, where it attains a large size and good color, though the latter character develops well at Pullman. None of the samples equaled in quality the variety as grown in New York. Those grown at Pullman had a very good flavor, though the flesh characters were those of poorly matured fruit. The fruit from the western part of the state was of a fairly elongated conic form, while that grown at Pullman was shorter and strongly ribbed. This variety appears to be but poorly adapted to Washington conditions. The fruit grown at Pullman wilted badly late in the season, while that from western Washington rotted considerably owing to fungus infections.

Wagener.—Though of the Northern Spy class, the

Wagener displays a much better balance of adaptation to the conditions of the state than the Northern Spy. It seems to reach its best development in the cooler regions of the state. The specimens from Grandview were of good size and very juicy, but were poor in color, coarse in texture, and deficient in flavor. Wagener develops especially well in the Spokane Valley. The specimens from Opportunity were large, well colored, and of excellent quality, though somewhat coarse in texture. Those grown at Pullman were more aromatic but possibly not so rich in flavor and did not develop sufficient size. This variety does well west of the Cascades and especially in the northern part of the Puget Sound Basin. The specimens from Eastsound were large, highly colored, and fine in texture, but less aromatic than the eastern Washington fruit. The samples obtained from West Virginia gave evidence of having been grown too far south. They were poorly colored and of rather poor texture, but of good size and excellent flavor. In form the fruit from Opportunity was roundish, that from Eastsound roundish conic, while the remainder was decidedly flattened and all samples were more or less strongly ribbed. This variety shows very little tendency to wilt in storage. The fruit from the highlands keeps well, but that from the irrigated valleys shows a tendency to physiological decay. Scald is serious after midwinter.

White Pearmain (*White Winter Pearmain*).—In general appearance this variety often closely resembles the Yellow Newtown, but is usually more elongated and more largely blushed. Moreover, it is quite different in flavor and is remarkable for its fine aroma. It is a variety of high quality and attractive for a yellow apple, moreover, it attains its good qualities in the irrigated valleys better than on the highlands, the specimens from Cloverland being dull and green in color and poor in texture, but well blushed and highly aromatic. Its worst fault is susceptibility to the apple scab. It would seem to be better adapted to growing in the state than some of the more

popular varieties. The fruit from the Yakima Valley retained its firmness much better than that from Cloverland, but lost somewhat in flavor toward the close of the season.

Willow (*Willow Twig*).—The writer has examined this variety only as grown in the elevated portions of eastern Washington. In such locations it does not develop especially well in either size or color and is of too poor quality to be worthy of consideration. Moreover, it wilts badly in storage, though when well grown the fruit has excellent keeping quality. It is evidently poorly adapted to this section.

Winesap.—In some of the irrigated valleys this variety is one of the most popular apples grown. It attains a good marketable size and an attractive color, though none of the samples examined were equal in color or quality to the Winesaps from Indiana and West Virginia. In elevated localities, as at Pullman, Cloverland and White Salmon, the fruit is small and poorly colored and has flesh characters indicating imperfect development and maturity. As grown in the irrigated valleys the fruit is apt to be deficient in flavor, and, if large, coarse in texture. The lot from Cashmere showed the best balance of characters of any Washington, grown specimens, but these were in no way superior to the Winesaps from West Virginia. It is probable that the better grown fruit from the eastern Winesap districts is equal to that grown in Washington in all respects, with the possible exception of size, which, if large, is, as noted, apt to be accompanied by deterioration in quality. It is evident then, that the balance of adaptation of this variety to northwestern conditions is imperfect at best and that the planting of Winesaps in Washington may easily be overdone. This variety proved to be one of the best in keeping quality. Those from Pullman and Cloverland wilted late in the season, though most of the other lots were in excellent condition in April and a few were held in storage until July.

Winter Banana.—As only a single lot of this variety

was examined in detail, it is difficult to make very positive statements regarding its behavior in the state. Though less desirable than a red apple, it is a variety of handsome appearance and is fairly good in quality. It is perhaps rather better adapted than the average to certain sections of the state and appears to develop best in fairly elevated situations. It is especially well liked in the Spokane Valley, and fruit grown there is said to have good keeping quality, though the specimens from western Washington were past season by midwinter. They wilted badly and showed much scald.

Yellow Bellflower.—This variety appears to be better adapted to the western part of the state than to the irrigated valleys. The apples from Clarkston were coarser in texture, milder in flavor and poorer in quality than the samples received from the east. There were no very striking differences in form, structure or appearance except that the eastern Bellflowers were more often blushed than those from Clarkston. The apples from Puyallup were overgrown specimens from young trees, were coarse and spongy in texture, and inferior in quality. As this is a tender fruit, easily injured by careless handling, and does not appear to be especially well balanced in its adaptations, it is not desirable to plant extensively for shipping. Moreover, it is not a good keeper. The specimens from Puyallup were practically past season when received and those obtained from the east were more or less injured and such specimens decayed quickly. Some of the lot from Clarkston, however, kept sound and firm until past midwinter, but deteriorated in flavor toward the last.

Yellow Newtown.—When at its best, this variety has few equals. It is narrow in the limits of its adaptations and its successful culture in the eastern states is confined to small areas, where, however, it is in nearly perfect equilibrium with its environment. In many places in the northwest it is grown successfully, though it scarcely equals in quality the best eastern product. The fruit from White Salmon and some of the irrigated districts

was of excellent quality, but coarser and less delicate in texture and of not quite so good flavor as the apples from West Virginia. The specimens from Cloverland were hard and green and gave evidence of imperfect maturity. Evidently the elevation is too great for its proper development. The single sample from western Washington consisted of well-colored, extensively blushed fruit, but was inferior in quality. Owing to its limited area of successful production in the east, it is worth planting in Washington wherever its characters give evidence of a fair degree of balance of adaptation with the environment. This variety is perhaps a better keeper than Winesap. Some of the fruit from White Salmon kept in good condition until July, though overgrown fruit and that which has been exposed to heat before storage showed signs of physiological decay late in the season. Underdeveloped specimens wilted in storage.

York Imperial.—In sections of Virginia and neighboring states the York Imperial occupies the place of supremacy held by the Baldwin farther north. This is doubtless due to its perfect balance with the environmental conditions of that region, and, like the Baldwin and other sorts perfectly adapted to their eastern habitat, this variety finds itself out of equilibrium when moved to the northwest. The apples from western Washington were of good size and color, but were coarse and undesirable in texture and poor in quality. The specimens grown at Pullman were smaller, more elongated, and less compressed than the others, and the axes were less oblique. They were somewhat better in quality, though not good enough to justify more extensive planting. The fruit wilted in storage, and that from western Washington gave evidence of fungous infection and scalded badly after midwinter.

DISCUSSION OF THE EFFECT OF ENVIRONMENT UPON APPLE CHARACTERS

Size.—Size is the direct result of development. An apple will reach its maximum in growth when all factors

are at the variety optimum for the physiological processes upon which development depends. A departure from this optimum, whether toward a greater or less intensity, means a decrease in size, as is observed in approaching either the northern or southern range of a variety. It has been frequently noted, however, that the optimum for growth is not the best combination of factors for the development of certain other desirable characters, so that it is well to choose an environment having certain factors in a somewhat less degree of intensity, being content with fruit of fair size but superior in other respects. Since the apple contains about 85 per cent. of moisture it is evident that the water supply is a factor of prime importance in determining size. It is possible by excessive irrigation to force an abnormal growth of the fruit, though always apparently at the expense of texture, flavor, and keeping quality. It is evident, then, that if fruit of good quality is expected, irrigation must be moderate in amount, especially with vigorous young trees. Thinning may result in increased size owing to the larger amount of moisture available for each fruit. Temperature and length of season are of importance in determining, respectively, the rapidity of growth and degree of development attained.

Form.—One of the striking features revealed by the study of a number of varieties from several localities is the fact that the modification in shape due to the difference in environment is by no means uniform for the several varieties. Some varieties are quite constant in shape while others are much more plastic in this respect. Moreover, certain varieties are much more easily influenced than others which respond in the same way, while still others respond differently to the same factors. One of the most frequently observed and conspicuous modifications of form consists of the elongation of the axis of the fruit relative to the horizontal diameter. This character has been especially studied, in the case of the Ben Davis, by Shaw, who found the elongation most noticeable in fruit from the northeastern states, the mari-

time provinces of Canada, and the Pacific coast. Shaw's papers dealing with this subject have already been noted. Upon studying the climate in these localities, it was found that the temperature for two or three weeks after the blooming season was notably lower than in the sections where the Ben Davis assumes its normal shape. Since this appeared to be the only factor constant for the several localities, it is suggested as the explanation of this variation. It has been shown, however, that temperature is incapable of influencing form except by its action through the functions of the plant in modifying the effect of some other factor. It is the writer's opinion that the elongation is due to the relative moisture supply of the different parts of the apple at this period of development as influenced by the temperature; that it is primarily a modification due to the moisture relation rather than to the direct effect of temperature, the latter being a secondary cause. The rapidity of circulation of the sap and therefore the supply of moisture to the organs of the plant is greatly influenced by the temperature. It is a well-known fact of plant physiology that much less moisture passes through the plant in the cool days of spring than during the warmer weather of midsummer. A reduction of the temperature at this time results in a still more sluggish movement of the sap. In the period immediately after blooming the energy of the plant, so far as the development of the fruit is concerned, is directed primarily to the proper nourishment of the growing seeds and the adjacent parts. If at this time the circulation of the sap is retarded by a temperature unwontedly low for the variety, the moisture supply of the fruit is lessened and a relatively larger amount goes to the seeds and adjacent parts, while the pulpy portion of the fruit receives a more scant supply. As a result, the axillary development is proportionately greater than the swelling of the fruit due to the accumulation of moisture in the superficial tissues. After some two or three weeks the form of the fruit becomes fixed and is not noticably influenced by the moisture supply thereafter.

The elongation of the fruit is usually accompanied by a constriction of the apex resulting in a conical form. This may be due to the greater development of the basal portion, which is adjacent to the point where the sap enters the fruit and may therefore be better supplied, though the physiology of fruit development is in need of further study. In the Grimes, however, an oblong form results. The McIntosh, as grown at Pullman, is often decidedly obovate, a variation which the writer ascribes to the same influences that produce the elongated conic form of the Ben Davis and other varieties, though in this variety the response is somewhat different. The Rhode Island Greening, Willow and Wagener, as a rule, fail to assume an elongated form in localities where it is well marked in some other varieties. Also in certain varieties which are naturally conic in form and considerably elongated, as Delicious and Yellow Bellflower, this effect is not evident. The larger number of varieties, when grown in this state, have a more ribbed form than the same varieties in the east. This seems to be due to a lack of balance in adaptation, though the particular factor which gives rise to the variation has not been determined. Some varieties, like the York Imperial and the Yellow Newtown, are compressed in form, that is elliptical in section, and have an oblique axis when grown in certain environments. These characters seem to be in some way related to the better development of the fruit, as they are less evident in fruit from the elevated and unfavorable sections of the state. Beach has noted in the "Apples of New York" a similar difference between the Newtowns of western New York and those of the Hudson Valley, the latter having a more oblique axis and elliptical form.

Stem.—The stem is one of the most variable structures of the apple, and, owing to the fact that stems of different lengths, diameters and shapes are commonly found in any lot of apples grown under practically uniform conditions, it is difficult to associate such variations with the environment. The writer has noted, however, in the case of some short-stemmed varieties, like the York Imperial,

that those lots grown under less favorable conditions had, on the average, longer stems than others grown under a more favorable environment.

Cavity.—The most conspicuous variation in the cavity is in its depth. This is of especial note in the Rome, which has a very shallow cavity in most parts of the state. This is doubtless due to the same cause which produces the elongated form of the fruit in many varieties, namely the elongation of the axis resulting from a deficient moisture supply incident to a low temperature after the blooming season. In this variety the elongated axis obliterates the cavity instead of modifying the general outline of the fruit. The same variation is also noted to a less degree in a number of other varieties. An especially furrowed cavity is often observed associated as a rule with the ribbed form of fruit.

Calyx.—The writer has failed to observe any modifications of importance in the calyx lobes of the fruit. The size of the calyx cup or "eye" of the apple is influenced by the development of the fruit. In large fruit this opening is apt to be large, so that the lobes are separated, resulting in an open or partly open calyx. Small or poorly developed apples, on the other hand, usually have the calyx closed.

Basin.—The depth of the basin seems to depend upon the same factors as that of the cavity and seems to be much more readily influenced than the latter. The width is often associated with the form of the apple, a very constricted apex resulting in a narrow basin. A much furrowed basin results from a combination of factors unfavorable to the best development of the fruit.

Skin.—Statements have often appeared in regard to the effect of various climatic factors upon the thickness and toughness of the skin. Estimates of these characters, however, appear to be based entirely upon sense impressions of the observers, although it would seem that exact measurements would not be especially difficult. In the absence of such accurate data, an expression of opinion

would be premature. Dry air and sunshine are favorable to the production of clear, smooth skin.

Color.—There seems to be no doubt that the coloration of apples depends upon the influence of several factors of which light is usually the most important. The importance of light is easily demonstrated by covering the fruit during development either wholly or in part. The intensity of illumination is also, evidently, quite narrow in its limits, so that a point is soon reached at which the color begins to pale owing to excess of illumination. It has been frequently noted that apples grown near the southern limit of the range of a variety are paler than those grown farther to the north. This effect appears to be the result of an excess of the two factors, heat and light. It has been mentioned in the discussion of the characters of several varieties that, contrary to the general impression, those grown in Washington east of the Cascades where insolation is intense were less highly colored than those from western Washington or the eastern states. The most marked example of this kind which the writer has observed is the Northern Spy. Again, contrary to the general impression, most of the samples from elevated locations were poorly colored, a fact which may be attributed partly to the strong insolation and partly to the poor development due to the low summer temperature. It appears, therefore, that either too strong or too weak illumination may result in poorly colored fruit and that the best color is developed under a condition of optimum intensity of the light.

It is suggested above that temperature may influence color. This is most commonly observed in the case of apples grown under conditions of too high summer temperature, though a deterioration in color also results if the temperature is much below the optimum for the variety. It is often stated that apples become more highly colored the farther north they are grown. This is only true in part. Those varieties which are adapted to the most northerly portions of the apple belt are able to develop their highest

color at the limit of winter hardiness of the tree. The southern varieties, on the other hand, require for the best development of color a higher summer temperature than is experienced in the northern localities. The Winesap, for example, when grown in Central New York is partly covered with a pale red. At Pullman the majority of varieties color poorly, due at least in part to the cool climate. That the temperature and not the shortness of the season is the factor involved is shown by the fact that most of these varieties color well in central New York which has a season of about the same length though averaging several degrees warmer.

Cultural conditions may influence the color to a certain degree. In general those processes of orchard management which favor the early maturity of the fruit result in improved color, especially in localities having a short growing season. Pruning and wide planting are regarded as favoring high coloration by admitting light into the tree, though it is possible that in regions where the light is intense these factors may not be of so great importance in their effect upon color as in less sunny locations. Something has been said of the influence of the soil in the discussion of the literature and it has been noted also that studies of the effect of fertilizers upon the color have not yielded satisfactory or uniform results. The influence of iron compounds is worthy of brief discussion in this connection. It seems evident, from the chemical studies which have been made, that the red pigment includes iron in its composition. This has sometimes been assumed to mean that the chief requirement for highly colored fruit is the presence of plenty of available iron compounds in the soil. As a matter of fact, iron is also necessary to the formation of chlorophyll and most soils contain an abundance of that element for the purpose. From the chemical data compiled by Stewart[5] it appears that the ash of the fruit contains a much smaller proportion of iron than that of the leaves. It is logical to conclude, therefore, that soils containing suffi-

[5] Pa. Sta. Rept. for 1910–11.

cient iron for the development of chlorophyll in the leaves are also fully supplied for the formation of the red pigment of the apple.

Internal Structure.—The form and relative development of the core and associated structures are subject to numerous variations, which, however, are seldom so conspicuous as to attract attention unless closely studied, and appear to be of little practical importance to either the grower or consumer of the fruit. The number of seeds may be mentioned as an indication of the thoroughness of cross pollination and in most varieties the presence of one or more well developed seeds is a requisite to the proper development of the fruit. Small or poorly developed fruit, the result of too short a season or too low a temperature, is apt to have the core closed and axile, or nearly so, while in the same varieties good development is usually associated with a more open abaxile core. The carpels of such poorly developed fruit are usually entire and smooth, while those of the better-grown fruit are more or less cleft and often tufted.

Flesh Characters.—From the standpoint of the consumer, these are by all odds the most important characters of the fruit, though lost sight of through the emphasis placed on external characters, and no grower who has at heart the permanent prosperity, extension and normal development of the industry can afford to look upon quality as a secondary consideration. Neglect in this matter is sure to result sooner or later in a bad reputation for the fruit among a considerable proportion of buyers, which appearance and advertising will not be competent to overcome. The fact can not be denied that the great majority of varieties fail to attain as high quality in the northwest as when grown in the eastern or middle states where nearly all of them originated, while at the same time they may excel in other important characters. This is especially true of most of the choice dessert apples. Such unequal development can have no other interpretation than that these varieties are in a state of unbalanced adaptation to the environment. This

fact being recognized, the main question is, How can this disadvantage be overcome? Evidently the solution does not consist in a steadfast refusal to face the situation and vehement declaration that the fruit of any particular district is the best that can be produced. Such tactics, though well meant, can be permanently successful only when the statements are justified by the facts. If apple culture in Washington is to be maintained upon a sound basis it will be necessary first of all that growers shall exercise great care in planting to choose those varieties most nearly in equilibrium with the environment in the various sections of the state, at the same time avoiding over-irrigation or other errors in orchard management which may tend to an unequal development of the characters of the fruit, usually at the expense of quality. Even this, however, may be but a temporary makeshift, since few if any of the better varieties possess the requisite power of adaptation. It will be necessary first of all to determine if the variations which appear when apples are grown from seed in the northwest are more favorable in character than those which are displayed by introduced varieties. If such should prove to be the case the writer is under the conviction that the apple culture of the northwest should ultimately be largely made over on a basis of new varieties of local origin. A number of such varieties have already appeared, but unfortunately some of them have been chosen with little regard for quality. No work of greater value to the future horticulture of the region can be undertaken by the experiment stations of the northwestern states than the development of apple varieties of high quality and perfect adaptation to the various sections of their respective states.

The apples of high quality which show a fair degree of adaptation to the irrigated sections are Esopus, Yellow Newtown, Delicious and White Pearmain. The last was found by Lewis, of the Oregon station, to be one of the best pollenizers on every variety tested. Jonathan, Winesap and Stayman, though largely grown, shows in general a poorer balance of characters. In the more

elevated valleys Wagener, Delicious and McIntosh are doubtless most worthy of culture. The highlands of eastern Washington are very poorly adapted to the growing of winter apples, though some of the early apples do fairly well, among which may be mentioned Oldenburg, Gravenstein and Yellow Transparent. On account of the abundance of sunshine the Oldenburg develops a high sugar content for the variety which counteracts its natural acidity and results in an apple of pretty good dessert quality. Of the winter apples, Rome reaches good marketable size but the quality is not high and the eastern market should not be jeopardized by shipping this variety. The Palouse, an apple of local origin, is of much better quality, but has little standing in the market as yet. The Dutch Migonne, a variety from western Europe, shows a better balance of characters in eastern Washington than in most other sections of this country. It is of good size, fairly well colored and excellent in quality.

Many varieties popular in the eastern states color better west of the Cascades than in eastern Washington, though there is usually manifest a lack of balance in other characters. In certain respects the environment resembles that of western Europe and many of the varieties of cherries, plums, prunes, and other fruits of that country do very well here and, indeed, in other sections of the state as well, though in a number of instances varieties of northwestern origin are gaining in favor rapidly. Apple breeding, however, requires more time for its accomplishment and further importations of fruits, especially apples, adapted to the mild climate of western Europe would no doubt prove an advantage through the possible discovery of sorts adapted especially to the western part of the state.

Quality is not in itself a simple character. It depends upon all the characters of the flesh which determine the desirability of the fruit for eating, such as texture, juiciness, aroma and flavor. Fineness of texture evidently depends upon a proper combination of favorable factors.

Conditions favoring rank growth result in coarse texture, as was observed in several instances in the case of apples grown under irrigation, especially if the fruit was overgrown. Some of the fruit from young trees also was overgrown and coarse. Tenderness depends upon the development. Poorly grown, under-developed fruit grown where the temperature is too low or the season too short for the variety has hard flesh which becomes spongy rather than mellow toward the end of the storage season. Overgrown fruit of certain varieties, on the other hand, often shows lack of coherence between the cells, often accompanied apparently by larger intercellular spaces, and such fruit tends to become mealy as the season progresses. Juiciness is primarily a manifestation of the amount of moisture in the fruit, but is also associated with the tenderness of the cell walls and their tendency to break rather than to separate. In general an abundance of moisture results in juicy fruit though the juiciness is not in proportion to the moisture supply. The substances which give the apple its aroma are present in such small amounts that their investigation is difficult. They are volatile compounds and affect the flavor of the apple largely by their action on the sense of smell. A cool climate is favorable to their production and it was often observed that they were most strongly developed in the apples from elevated situations. Flavor depends upon the kinds, amounts and relative proportions of the soluble solids, especially the balance between sugars and acids, and will be given further consideration in the discussion of the chemical composition. Immature and under-developed apples contain some tannic acid, which is often sufficient in amount to give an astringent character to the fruit.

Keeping Quality.—In its relation to the environment, keeping quality evidently follows the same rule as other variable characters of the apple, namely, that for any variety the keeping quality depends upon the optimum intensity of the various external factors. Apples grown where the temperature is too low or the season too short

to develop the fruit to a proper stage to keep well, soon wilt, lose flavor and scald, or show other evidence of deterioration as was frequently observed in the fruit from high altitudes. On the other hand, too great excess of certain factors results in overgrown or overripe fruit having a tendency to rot, mealiness, or physiological decay, as in the case of the Yellow Bellflowers from Puyallup and some of the fruit from the warm valleys. The balance of factors favorable to good keeping quality does not appear to differ much from that which produces the fruit which is most desirable in other characters, though it is possible that the required intensity of some factors may be slightly lower. It appears, therefore, that a good balance of the other characters of the fruit and perfect adaptation to the environment will be accompanied, as a rule, by good keeping quality, provided that the fruit is properly handled and not infected with disease, while an unbalanced adaptation of characters to environment is likely to result in poor keeping quality. It seems probable that irrigation in itself does not result in poor keeping except when improperly applied or carried to excess or associated with other factors in such a way as to destroy the equilibrium of the environment. The relation of specific gravity to the keeping quality is discussed in a succeeding paragraph.

Specific Gravity.—It has long been understood that varieties of apples differ in their relative weights; thus Wolf River is comparatively light and Baldwin is generally regarded as a heavy apple. The only record found of the determination of specific gravity of apples is that of Howard's work in the National Bureau of Chemistry, Bulletin 94, in which it is noted that the specific gravity diminished 3 per cent. to 5 per cent. during storage. From the account it is not clear whether the determinations at the different dates were made with the same apples. The decrease of specific gravity is ascribed to the increase of air spaces between the cells due to the softening of the middle lamella. In the specific gravity determinations made by the writer a number of points was noted.

The different lots of a variety may differ considerably in specific gravity, though as a rule running somewhat close together, thus Ben Davis and Gano are apples of low specific gravity, while Grimes, Stayman, Wagener, and Yellow Newtown run rather high and Baldwin and Rome may be classed as medium in this respect. Overgrown apples were low in specific gravity, probably owing to more air space between the cells. This is more apparent upon examining the results for individual apples than upon comparing the average for different lots, as in the latter case the extremes are modified by averaging with the results for more normal specimens. On the other hand, small and rather undeveloped apples are apt to have a high specific gravity on account of their solid flesh and usually closed core. Juicy apples, if not overgrown, have a high specific gravity when the juiciness is due to a high moisture content.

The relation of specific gravity to keeping quality is of interest. While some late keeping varieties have normally a low specific gravity, those lots of a given variety having a high specific gravity for the variety are usually the best keepers. This is in line with the fact that certain causes which give rise to fruit of poor keeping quality also produce a low specific gravity. This is shown very strikingly by a comparison of the specific gravities as calculated month by month through the season. As the calculations were made at the time the fruit was found fit for use, the monthly averages show the steady increase in specific gravity with the better keeping quality of the fruit, though modified somewhat by the peculiarities of the different varieties which happened to be in season at different times. These averages are as follows: November and December, 0.787; January, 0.787; February, 0.810; March, 0.831; April, 0.852. Though these results may seem to be at variance with Howard's observations it is possible that if the same specimens had been tested at intervals a decrease in specific gravity would have been noted.

Chemical Composition.—In order to throw some light,

if possible, upon the relation of chemical composition to the other characters of the apple and to determine whether the composition is influenced by the environment, the juice of the various samples of Grimes, Jonathan, Winesap and Yellow Bellflower was analyzed by the department of chemistry.

The juice of the Grimes and Winesap contains, as a rule, a decidedly higher percentage of total solids than that of the Jonathan and Yellow Bellflower. It is also generally higher in specific gravity and has a greater viscosity. In Grimes and Yellow Bellflower the juice of the eastern-grown fruit contains a large proportion of total solids than that of the Washington grown fruit, though this rule does not hold good in the other varieties. The apples from the irrigated valleys and western Washington were low in total solids with the single exception of the Winesaps from Cashmere. The analyses fail to show any constant difference in sugar content in favor of the fruit produced in the sunny climate with long hours of daylight characteristic of the apple-growing sections of the state.

In Grimes the total sugars are fairly high and the proportion of sucrose is especially large. The acid content, on the other hand, is low as a rule. The result is a rich, mild or nearly sweet flavor. A sample from Puyallup showed the lowest sucrose content combined with the highest acid content, and this was the least rich as well as the most acid in flavor.

Jonathan, on the other hand, displays a low content of total sugars and especially sucrose, while the acid content is slightly higher than in Grimes, indicating a subacid apple, lacking in richness. The lots from Missouri and Indiana were highest in sucrose but were of scarcely as good quality as the Jonathans from West Virginia. The latter were low in both sucrose and acid, but displayed a good balance between these constituents, indicating an apple with rather thin juice, not very rich, but pleasant and refreshing. Its evident superiority resulted largely

from the fine texture and well-developed flavoring constituents not shown by the analysis.

The Winesaps, though high in total sugars, are low in sucrose, indicating a heavy juice rather lacking in richness. The comparatively high acid content corresponds to the sprightly subacid character of the fruit. The highest acid content was found in the fruit from Cloverland, where it is associated with a total lack of sucrose resulting in a comparatively poor fruit. The apples from Cashmere and White Salmon were also devoid of sucrose in the juice, but the acid content was low and the flavoring principles well developed, as a result of which the quality was fairly good. The poorly developed Winesaps grown at Pullman were deficient in sucrose, acid, and flavors and were correspondingly poor in quality.

The Yellow Bellflowers, though low in total sugars, were rather high in sucrose and also in acid. The balance between these constituents is good and results in a moderately rich, pleasant, subacid flavor.

SUMMARY

The opportunity for the study of apple variation was unusually good, owing to the facilities afforded for the examination of fruit from various localities and different environments, and it has been possible to work out the fundamental principle upon which variation resulting from external factors depends and to apply it in the study of environmental adaptations. This principle, the *Law of the Optimum,* states that, for any given variety there is for each character a certain intensity of each essential factor of the environment at which, other conditions remaining the same, that character reaches its highest development.

In the application of this law to varietal adaptations, the essential point is the proper balance between characters and environmental factors, that is, all factors should be of such an intensity as to permit a good all-round development of the fruit. In the absence of such

a balance certain characters may fail to reach a proper degree of development while others develop to excess.

The failure in quality and other respects of many of the best dessert varieties of apples when grown in Washington is due to such a lack of balance. Practically all of them originated under a much different environment and were selected and came into prominence owing to their perfect balance of adaptation in localities having a set of external conditions similar to those under which they originated. The hope of northwestern apple culture in the future lies in the careful selection of varieties and the origination locally of varieties of high quality showing adaptation to the conditions of growth in the various sections. In the meantime plantings should be made from those varieties of high quality which show the best adaptation. These are Esopus, Yellow Newtown, White Pearmain and Delicious for the irrigated valleys, and Wagener, Delicious and McIntosh for the higher valleys of northern and eastern Washington. Jonathan, Stayman and Winesap show a poorer balance and should not be planted too recklessly. The climate of the Pacific coast resembles that of western Europe more than that of the eastern states, and further importations of European varieties is desirable especially for testing west of the Cascades.

The moisture relation is probably the most important factor in inducing variations, and is doubtless responsible for certain variations which have been ascribed to other causes which act indirectly by modifying the moisture supply. The elongation of the fruit following a cool period after blooming may result from a diminished circulation of the sap, giving rise to an insufficient supply to provide for the simultaneous development of the fleshy portion and elongation of the axis. Variation in the depth of the cavity and basin in certain varieties is probably to be explained in a similar way.

Color modifications depend to a great extent upon the light relation and somewhat upon development as influenced by temperature. The optimum intensity for the

production of red pigment is quite narrow in most varieties and poor color may result from either deficiency or excess. Latitude and altitude affect the color only as they modify the factors upon which color depends, causing them to approach or recede from the optimum. The influence of elements in the soil is not well understood. It is probable that soils containing sufficient iron for the proper development of chlorophyll contain an abundance for the production of red pigment in apples.

Aside from such differences as depend upon the handling of the fruit, variations in keeping quality appear to follow the law of the optimum in the same manner as the other characters of the fruit. Conditions which favor the best all-round development result, as a rule, in good keeping quality. Apples grown under irrigation are said to keep poorly probably because of their unbalanced adaptation to the environment. Certain factors which favor development and maturity are present in excess, resulting in overgrown or overripe fruit.

Varieties differ in specific gravity according to the extent of intercellular spaces in the flesh and the openness of the core. Overgrown specimens are low in specific gravity. As a rule, those lots which kept best in any variety had the highest specific gravity.

Chemical composition is associated somewhat with quality. High sucrose content results in richness of flavor. Fruit of high quality has the sugars and acids well balanced and the flavoring constituents well developed. A heavy juice is usually associated with a high content of soluble solids. Fruit grown under irrigation is ordinarily rather low in soluble solids. There seems to be no constant relation between the amount of sunlight and the production of sugars, and flavors appear to develop best in a relatively cool climate.